# Influence of feed rate and threaded length in thread forming and tapping operations

Conference or Workshop Item

# Influence of Feed Rate and Threaded Length in Thread Forming and Tapping Operations

Igor C. Pereira [a], Alvaro E. Faria [b], Marcio B. Da Silva [a]

*Abstract*—**Internal threading are complex and critical operations. Complex due to tool geometry and the need for synchronisation between feed movement and tool rotation, and critical for being at the last stages of the manufacturing process of a component. The main objective of this study is to evaluate the influence of feed rate (the thread pitch) and thread length on measured torque and thrust forces in the processes of thread forming and tapping machining. Forming and cutting taps M10x1.5 are used with mineral oil as the cutting fluid required by the internal threading process. The results show that feed rate has a strong influence on axial force. However, threaded length only has an influence when compared with the length of the tapered portion of the cutting tool.**

***Index Terms*—Tapping operation, Thread forming, Machining.**

## I. INTRODUCTION

The process of internal threading is of significant importance in the metalworking industry. It is usually one of the last operations on a part that has already been under multiple manufacturing processes and therefore is of high value. This is of great concern as an operation failure in high added value pieces is bound to generate high costs [2]. Furthermore, threads are typically manufactured to allow the joining of two or more pieces, implying that the operation should allow for a good geometric tolerance [1].

In industry, the process of tapping is more common than thread forming. Internal threading with the use of tap cutting tools is a highly complex process due to features such as difficulty of chip removal in blind holes and when cutting materials that form short chips. It is also more difficult to lubricate. Lubrication is more important than cooling action as this is a process performed at low cutting speeds. The need for perfect synchronisation between cutting and feed movements, together with the need for fast spindle reversion at the thread end, justify the low cutting speeds adopted in these operations [7]. Problems are even more complicated in deep threads. An automatic tapping operation also demands, besides other features, specific tool holders or machine tools that limit the maximum cutting speed.

The internal thread forming presents no difficulty to remove the chip, since there is no chip formation. However, it has limitations on the type of material to be machined, being indispensable minimum ductility necessary for the deformation of the material. According to [3], the internal threading operation by forming (or lamination) is a process that has increasingly been used in industry. This is a very interesting process and economically beneficial compared with machining by cutting operation. It provides a greater tool life, improved reliability and cleanliness because it does not produce chips. However, threads produced by the tapping operation have better dimensional tolerance. Tapping is a machining operation where threads are formed by chip formation. In thread forming operations, threads are formed by plastic deformation of the workpiece material. A split crest at the top of the thread is usually inevitable [8], as illustrated in Fig. 1.

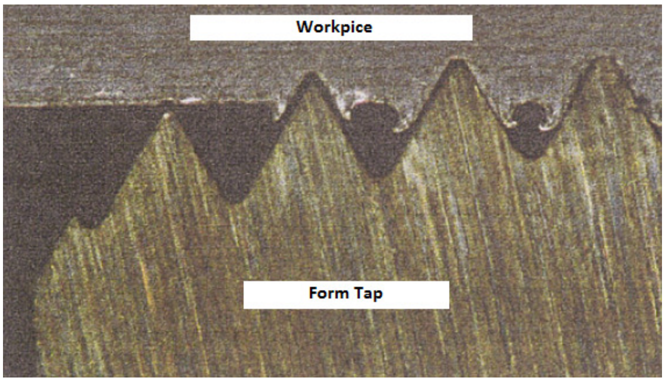


Fig. 1. Thread forming operation and the split crest [5].

According to [1], the major advantage of the thread forming process relies on some features in the threads. Usually, threads produced by forming process have higher mechanical strength than machined threads. However, this depends on the material. [6] determined the tensile strength of internal threads manufactured by forming process in aluminum alloy 7055. The results demonstrated that threads produced by forming had the same mechanical strength than a machined thread when comparing at the same production conditions.

In both cutting and forming processes, the use of a rigid holder can mean an increasing thrust force on the tap and on the workpiece due to synchronous error [4].

The main objective of this work is to investigate the effect of feed rate variation, simulating a synchronism error between rotation and feed movement, and thread length on the axial force and torque for threads manufactured by both cutting and forming operations.

## II. METODOLOGY

Tests were carried out to using tools to produce M10x1.5 threads by machining and forming. The cutting tool tap was a HSS uncoated tool M10x1.5 6H with 3 flutes and 5 teeth in the tapered region. The forming tool was a HSSE TiCN coated tool, 6HX-B, with 8 lobes. Tests were performed on a machining center using rigid tool holder. The thrust force

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and torque during the operation were measured with a Kistler rotating dynamometer type 9123C, stator type 5221B1, cable type 1500B19 and signal conditioner type 5223B. The signals were acquired using a data acquisition card and stored in a computer. The material of the workpiece was an AISI 1045 carbon steel with dimensions of 16 mm x 19 mm x 250 mm and average hardness of 208 HV.

Threads with different lengths were manufactured to investigate the effects on thrust force and torque. The thread lengths were: 3, 6, 9, 12, 15, 30 and 40 mm. To simulate synchronous errors, various feed rates were used in the machine tool program, namely 1.480, 1.490, 1.495, 1.500, 1.505 and 1.510 mm/rev. In the test where the thread length was variable, the feed rate was constant at 1.500 mm/rev, while for the test with varying the feed rates the thread length was 15 mm. The cutting speeds (or tangential speed in the case of forming process) were: 10 and 30 m/min.

## III. RESULTS AND DISCUSSION

Fig. 2 shows the full cycle of a typical thrust force behavior for a tapping operation at cutting speed of 10 m/min. For this cutting condition, rotation is 318 rpm and consequently feed velocity is 8 mm/s. Thread length is 16 mm, so that the thread is ready in 2 s. However, the tool will travel a further 10 mm to avoid the effect of deceleration. Note from Fig.2 that for this condition, the highest thrust force is about 260 N (at approximately 5.5 s) in the cutting cycle, and 275 N (at 7.5-8.0 s) in the return cycle. The decrease on the thrust force will not be discussed here, as it may be related to the machine tool characteristics to maintain the synchronism during movement. However, the torque signal which behavior is more directly related to the operation cycle is presented in the plot of Fig. 3. Note that the torque increases within 0.5 s to about 6 N.m where it stays practically constant at this level during cutting, after what it decreases to no torque within 0.6 s.

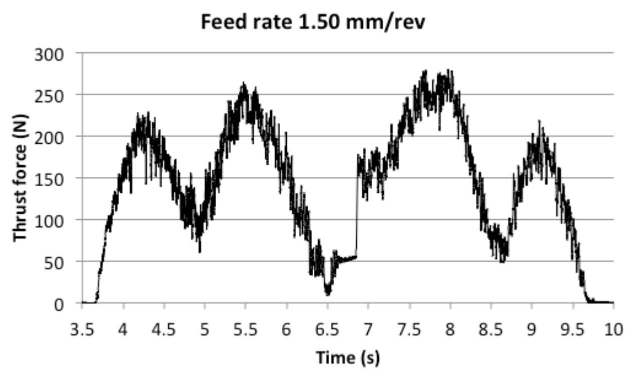


Fig. 2. Thrust force during the tapping operation of AISI 1045 carbon steel at cutting speed of 10 m/min. Thread length is 16 mm with a feed rate of 1.500 mm/rev.

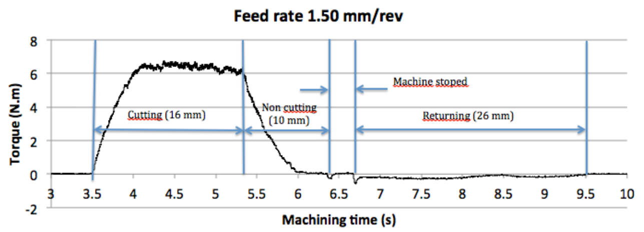


Fig. 3. Thrust force during the tapping operation of AISI 1045 carbon steel at cutting speed of 10 m/min. The thread length is 16 mm and feed rate was 1.500 mm/rev.

### A. *The effect of feed rate on thrust force*

The plot in Fig. 4 shows the variation of the axial thrust force signal in time with feed rate for a cutting speed of 10 m/min.

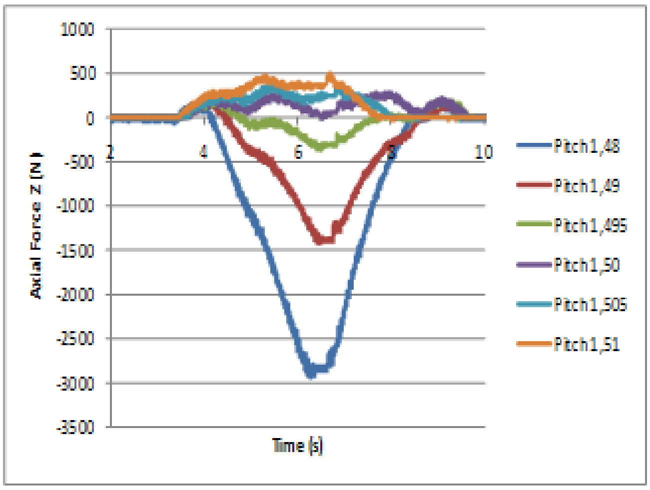


Fig. 4. Axial force for tapping operation of AISI 1045 carbon steel at cutting speed of 10 m/min.

It can be seen from Fig. 4 that the axial forces are negative and have high values when feed rates of 1.500 mm/rev or higher are used. The feed rate value that produced the lowest force values was 1.500 mm/rev, however, this does not mean that this is the most appropriate value to be used. The results suggest that an optimal feed rate is between 1.495 and 1.500 mm/rev.

The time plot of Fig. 5 shows the variation of the axial force for a cutting speed of 30 m/min.

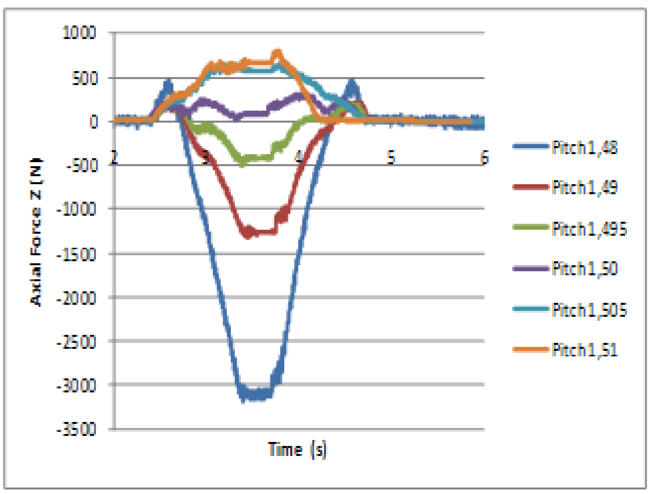


Fig. 5. Axial force for tapping operation of AISI 1045 carbon steel at cutting speed of 30 m/min.

Note that the axial force values in this plot are very similar to the values measured when machining at 10 m/min. It seems that this cutting speed variation has not had much influence on the values of axial force. This result still suggests an optimal feed rate between 1.495 mm and 1.500 mm.

The time plot of Fig. 6 shows the variation of torque signal for a tapping operation at 10 m/min cutting speed. The red circle in the plot highlights the torque signal at the end of the thread (after 16 mm). It can be seen that signals for feed rates higher than 1.500 mm/rev show a "peak" in this region and the signal for feed rates lower than this value display a small "valley".

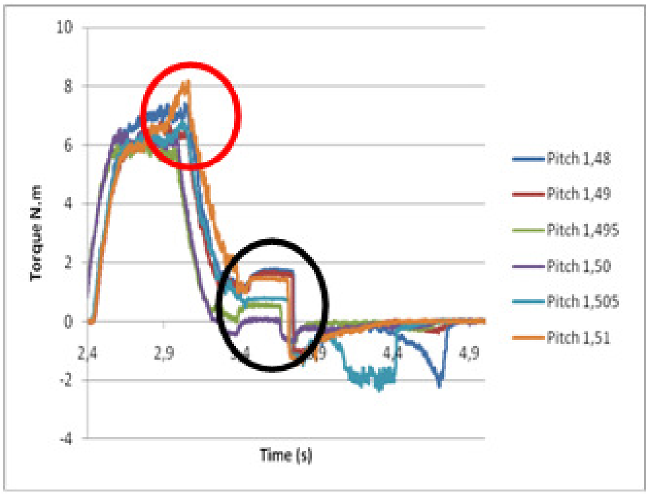


Fig. 6. Torque signal for tapping operation of AISI 1045 carbon steel at cutting speed of 30 m/min.

Another region highlighted by the black circle in the graph of Fig. 6 is the time when the machine stopped before the inversion of the movement. Operations using feed rates different from 1.500 mm/rev can be easily identified by the value of the torque. For through holes this value should be zero. If however there is a sync error or even a feed rate error in the program, this will be perceived by the behavior of the graph. The behavior of the torque at this region is independent of the feed rate.

The graphs in Fig. 7 and Fig. 8 show the effects of feed rates in the thread forming operation for speeds of 10 m/min and 30 m/min respectively. Note that a similar general pattern of behavior (or shape) is observed on both graphs except for the actual measured values. For this operation, an ideal feed rate is also close to 1.495 mm/rev.

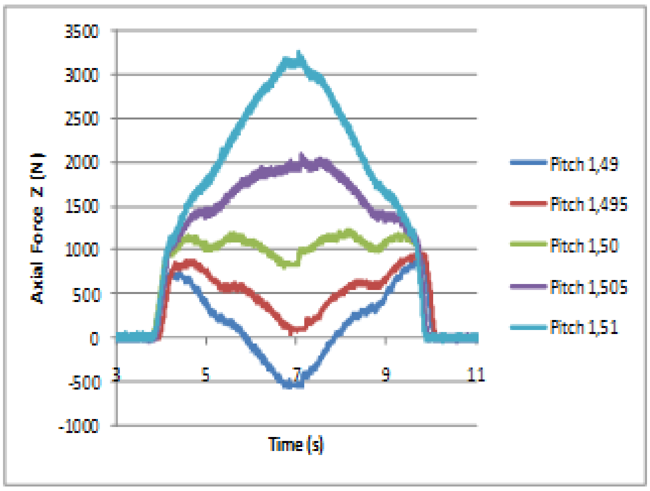


Fig. 7. Axial force for thread forming operation at speed of 10 m/min.

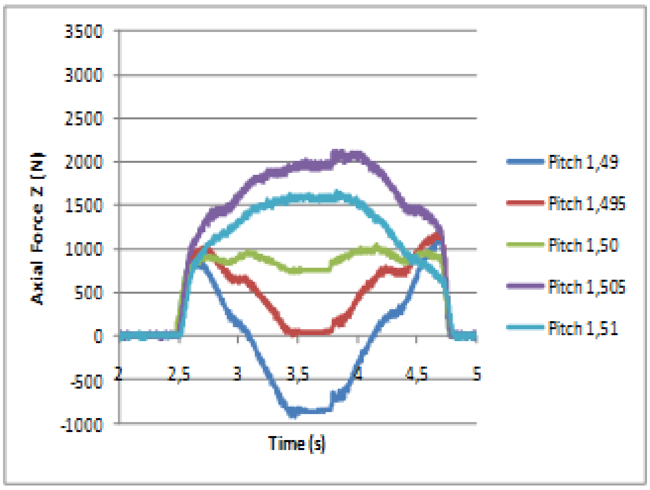


Fig. 8. Axial force for thread forming operation at speed of 30 m/min.

For a speed of 10 m/min the thrust force is close to 1200 N while for a speed of 30 m/min there is a decrease in all feed rates except for the 1.490 mm/rev pitch. At a feed rate of 1.500 mm/rev the thrust force is close to 1000 N, for 1.510 mm/rev it is close to 1600 N (compared to 2000 N for the 10 m/min speed). For a feed rate of 1.490 mm/rev, the smaller used, the force is close to -500 N at the 10 m/min and -900 N at the 30 m/min speed.

### *B. The effect of thread length on thrust force*

This section analyses the effect of the depth to which the tool penetrates into the workpiece, i.e, the thread length, on the torque signal. A speed of 10 m/min was used on the performed tests. The graph of Fig. 9 shows the variation of the mean torque with the threaded length during the tapping operation. Each point in the graph, represented by a cross, is the average torque of the three performed tests for each thead length. The error bar in each point corresponds to twice the estimated standard deviation and indicates an approximate 95% confidence interval for the mean torque.

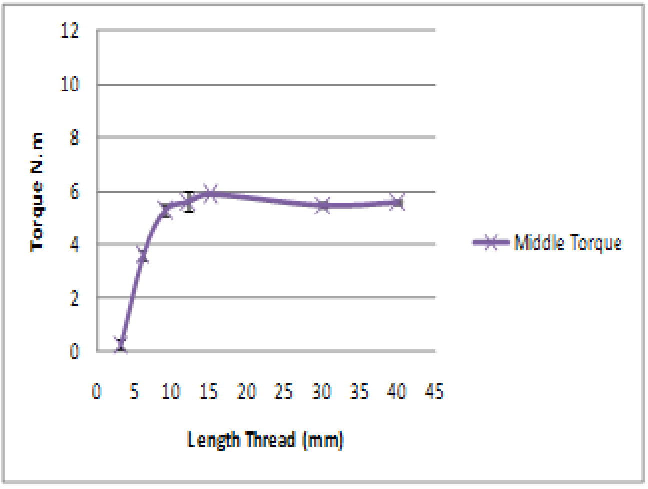


Fig. 9. Effect of thread length on the mean torque signal for tapping operation at cutting speed of 10 m/min.

Note that for thread lengths between 12 and 15 mm, the torque value stabilizes. Even with a significant increase in the thread length, four times the tool diameter, there is no increase in the value of torque. Recalling that the maximum length recommended by the manufacturer is 1.5 times the diameter of the tool, 15 mm for this work.

For a thread length of 3 mm, the mean torque is 0.5 N.m, whereas the torque for the length of 6 mm it is 6 N.m. This difference is due to the part of the tool that has contatct with the material of the workpiece. When the threaded length was 3 mm, only the first thread and the beginning of the second thread of the tap tool act as cutting tools, which means a cutting depth (height of the thread machined) less thatn 0.2 mm. The operation, which is performed basicaly only by the first tooth can be considered as micro machining.

Fig. 10 shows the torque signal for all machined thread lengths during the operations.

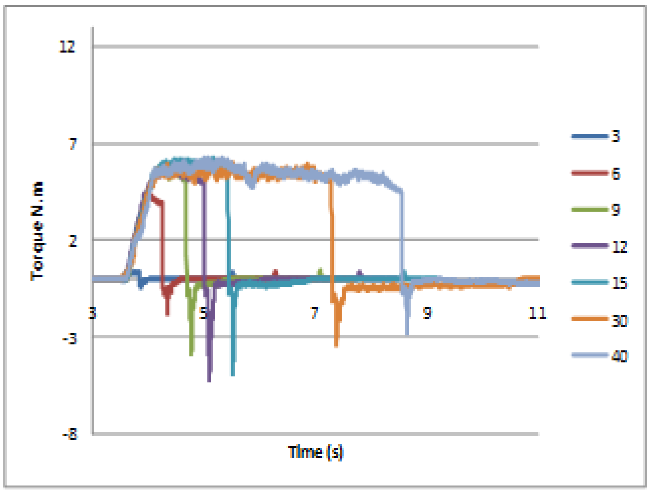


Fig. 10. Torque signal for different thread lengths when tapping at cutting speed of 10 m/min.

The inclined portion of the graph represents the action of the tapered portiong until the formation of the first full thread fillet, for thereafter entering all theet necessary to machine the thread. This means that for the length of 6 mm the first screw thread part has not been formed in full.

Fig. 11 shows the variatin of torque with thread length for forming operation.

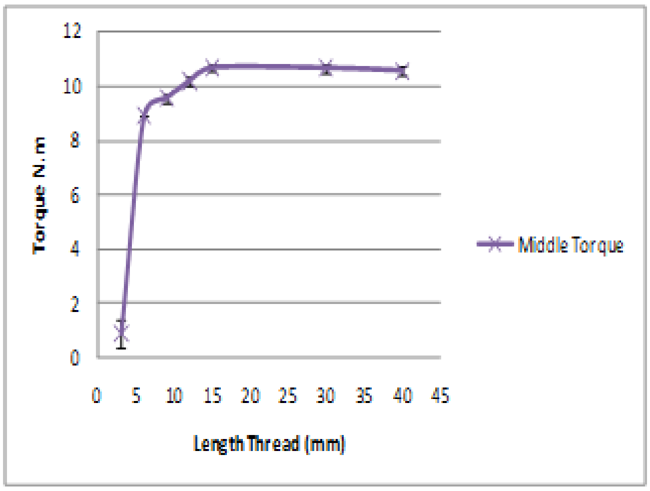


Fig. 11. Effect of thread length on the mean torque signal for forming operation of AISI 1045 carbon steel at speed of 10 m/min.

The mean torque is higher for forming operation as compared to machining. The average torque for all thread lengths is close to 11 N.m. The thread length has no effect in the torque for values higher than 15 mm. The tappered portion of the tool is smaller in forming tap than cutting taps.

The time plot of Fig. 12 shows the torque signal against the thread length for the forming operation.

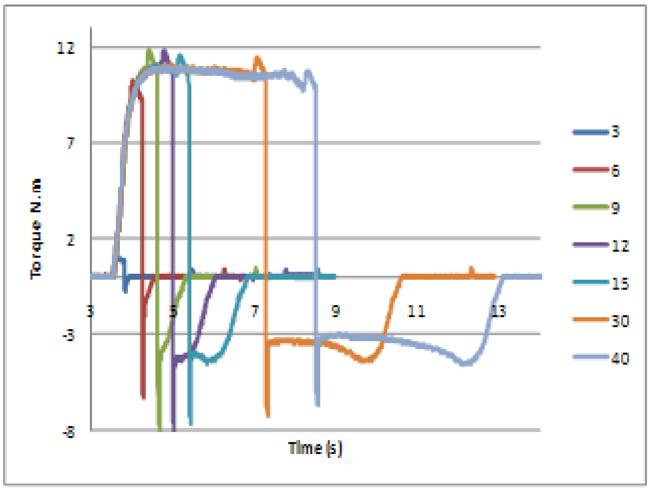


Fig. 12. Torque signal for different thread lengths for the forming operation at speed of 10 m/min.

## IV. Conclusions

The results obtained from the analyses in this work allow the following conclusions:

- The axial force increases with feed rate. A small variation in the feed rate can have a great effect in the thrust force.
- The feed rate has less effect on the torque.
- The ideal feed rate to be selected in the machine tool is a litle beat smaller than the thread pitch of the tool.
- The thread length has no effect in the torque or thrust force. There is effect only when the thread length is smaller than the tool chanffer.

## REFERENCES


[1] I. C. Pereira, *Analysis of Torque and Axial Force in Different Cutting Conditions When Tapping Alloyed Gray Cast Iron (CrCuSn e CrCuSnMo) and Compacted Graphite Iron ISO 350.* 2010. 100p. Master Dissertation, Federal University of Uberlandia. Uberlndia, MG, Brazil.

[2] A. O. Carvalho, L. C. Brandão, T. H. Panzera and C. H. Lauro, "Analysis of form threads using fluteless taps in cast magnesium alloy (AM60)". Journal of Materials Processing Technology. n. 212, p. 1753-1760, mar. 2012.

[3] Da Mota, P.R., Gonçalves, R.A., Reis, A.M., Da Silva, M.B., "Performance of high-speed steel taps at high cutting speed". Int. J. Machining and Machinability of Materials, v. 2, pp 299-308, 2007.

[4] G. Fromentin, A. Bierla, C. Minfray, G. Poulachon, "An experimental study on the effects of lubrication in form tapping". Tribology International. V. 43. P. 1726–1734. 2010.

[5] Agapiou, J.S., Evaluation of the effect of high speed machining on tapping", Journal of Manufacturing Science & Engineering Technology, ASME, 116, P 457 - 462. 1994.

[6] Catalogue "Emuge: Tapping Technology" www.emuge-franken.com

[7] D. Baldo, C. H. Lauro, L. C. Brandão, J. C. Fitteman. "Comparative study of the tensile strength of internal forming and machining threads". In: National Congress of Mechanical Engineering, 2010, Campina Grande, Brazil (in Portuguese). 2010.

[8] G. Fromentin, A, G. Poulachon, A. Moisan, B. Julien, J. Giessler, "Precision and surface integrity of threadsobtained by form tapping". CIRP Anals. V. 54. P. 519 - 522. 2005.